Bone mineral density precision for individual and combined vertebrae configurations from lumbar spine dual energy X-ray absorptiometry scans

Karen Hind[1] and Brian Oldroyd[2]

[1] *Department of Sport and Exercise Sciences, Durham University;* [2] *School of Sport, Leeds Beckett University.*

Abstract

The accurate interpretation of repeat DXA scan measurements and the understanding of what constitutes a true and meaningful change, requires knowledge of measurement error (precision) and least significant change (LSC). The interpretation of lumbar spine bone mineral density (BMD) in particular, can be confounded by artefacts and as such, the International Society for Clinical Densitometry (ISCD) recommends exclusion of individual vertebrae if they are affected by local structural change or an artefact. The aim of this study was to determine the precision of BMD measures of individual and various configurations of vertebrae from PA lumbar spine scans. The study group comprised of 30 women (age 36.3 ± 6.5 years; height: 165.2 ± 5.7 cm; weight: 67.7 ± 12.6 kg) who each received two consecutive anterior posterior lumbar spine scans (Lunar iDXA, GE Healthcare, Madison, WI), with repositioning. Precision error varied by individual vertebrae and by different configurations of vertebrae, but all were within the ISCD acceptable range of precision. For vertebrae configurations containing at least two vertebrae, precision error ranged from 0.005 - 0.008 RMS-SD (0.44 - 0.70% CV). Of the individual vertebrae, the lowest precision error was observed at L4, and from the different configurations, for L2L3L4 and L1L2L3L4. In conclusion, this study group demonstrated excellent precision for BMD measurements of individual and various configurations of L1 to L4 vertebrae using the GE Lunar iDXA densitometer.

Introduction

Central dual energy X-ray absorptiometry (DXA) measurements of lumbar spine and hip bone mineral density (BMD) are used for the diagnosis of osteoporosis, the assessment of fracture risk and for the monitoring of BMD change in response to factors such as ageing, menopause, lifestyle and medications. The accurate interpretation of repeat DXA scan measurements and the understanding of what constitutes a true and meaningful change, requires knowledge of measurement error. Once the precision error of a measurement is established, the least significant change (LSC) value should then be calculated and applied (1). The LSC is the change between two BMD measurements that is required for 95% confidence that an actual change has occurred. It is the smallest change observed before biological change can be assumed. The acquisition of accurate BMD measurements also requires an understanding of potential external sources of error such as drift in instrument calibration, incorrect patient positioning or region of interest placement, or non-exclusion of artefacts. The precision of DXA for the measurement of lumbar spine and hip BMD, across all manufacturers, is considered excellent. For the total hip, precision errors of 0.8 to 1.2% have been reported, and for the femoral neck, 1.4 to 1.6% (2). The anterior-posterior lumbar spine BMD measurement includes the L1 to L4 vertebrae. Precision errors (% coefficient of variation, CV) for this region have been reported between 0.8 and 1.0% (2-6).

Every DXA scan image should be scrutinsed for artefacts that may impact BMD interpretation. The interpretation of lumbar spine BMD in particular, can be confounded by artefacts and as such, the International Society for Clinical Densitometry (ISCD) recommends exclusion of individual vertebrae if they are affected by local structural change or an artefact, according to specific criteria (1). Artefacts can be internal or external. Internal artefacts include surgical clips, degenerative spine changes, vertebral fracture, aortic calcification, or indications of disease such as Paget's, or osteoblastic malignancies (1,7). Such artefacts can effect lumbar spine BMD if not excluded, for example, tantalum surgical clips present at L3 can lower BMD (7). The risk for external artefacts such as jewellery or aspects of clothing that interfere with scan acquisition (8 Krueger), should be avoided through careful pre-scan questions and perceptive observation by technologists. The effect on BMD can be similar to internal artefacts. Polyester clothing containing reflective strips, has been demonstrated to increase lumbar spine BMD by 0.008 g/cm^2 (8). The ISCD recommend that vertebrae with a focal structural defect (FSD) or with a T-score discrepancy with adjacent vertebrae that is greater than 1.0 should be excluded from the analyses, and a minimum of two vertebrae must be used for diagnostic classification (1, 9-10). To support this recommendation, the ISCD introduced an interactive Atlas of Focal Structure Analysis to improve interobserver agreement on vertebral body exclusion criteria (10-11).

Although vertebral exclusions can affect over one quarter of lumbar spine BMD scans (12), to date, no precision data have been published to inform on variations in precision across different vertebrae and different combinations of vertebrae. The aim of this study was to address this gap by determining the precision of BMD measures of individual lumbar vertebrae and specific combinations of vertebrae from PA lumbar spine scans.

Methods

Participants

Thirty women with no known disease, were recruited to the study. The age range of the participants reflected that of the usual population scanned at the Centre and the physical characteristics of the study group are presented in Table 1. The study was reviewed and approved by the University Research Ethics Committee and all women provided signed informed consent prior to taking part.

Table 1. Physical characteristics of the study group (n=30)

	Mean ± SD	**Range**
Age, y	36.3 ± 6.5	24.2 to 49.7
Stature, cm	165.2 ± 5.7	146.0 to 174.4
Body mass, kg	67.7 ± 12.6	44.6 to 86.4
Body mass index, kg/m^2	24.7 ± 4.1	16.7 to 32.7
Lumbar spine (L1-L4) bone mineral density, g/cm^2	1.219 ± 0.168	0.880 to 1.535
Lumbar spine (L1-L4) Z-score	0.3 ± 1.4	-2.5 to 3.0

DXA Scan Acquisition and Analysis

All lumbar spine scans were made on a GE Lunar iDXA densitometer using Encore software version 15.0 (GE Healthcare, Madison, WI). The iDXA has an ultra-stable X-ray tube, a narrow angle fan beam (4.5^{o}) and (64) Direct- Digital Cadmium Telluride (CZT-HD) detectors in staggered array which eliminates dead space between the detectors. This creates high resolution images with excellent precision. Two consecutive posterior-anterior (PA) lumbar spine scans were performed on each participant, with repositioning between scans. After the first scan, the participant dismounted the scanning table, stood up and was then repositioned back on the scanning table. There were no problems with positioning and all scans were conducted using standard scan mode. For each scan, the legs were elevated with flexion at the hip and of the knees at 90 degrees, and with the lower legs resting on the iDXA positioning foam block (GE Healthcare, Madison, WI). This positioning enables a widening of the intervertebral space so that individual vertebrae in the lumbar region are clearly visualised. Lumbar vertebrae L1 to L4 were analysed, all vertebrae were clearly visualised with no deformities, and there were no vertebral body exclusions. Quality assurance using the calibration block and quality control using the aluminium spine phantom were made during the study period, and no drifts were observed. Participants were scanned with a void bladder, and had abstained from intensive exercise, alcohol and caffeine, prior to scanning. One ISCD certified clinical densitometrist performed all scanning and analyses and minimal adjustments of regions of interest placements were made.

Statistical Analyses

Statistical analyses were performed using Microsoft Excel 2010. Participant demographics were analysed to mean and standard deviation (SD). Descriptive statistics (mean, SD and range) were determined for all data obtained from the scans to characterise and compare groups. Precision error was calculated as the root-mean-square standard deviation and root-mean-square percent coefficient of variation, and LSC values were calculated from the ISCD Advanced Precision Calculation Tool (www.iscd.com). All LSC values were calculated at the 95% confidence level.

Results

Descriptive results for the paired measurements for each individual vertebrae at L1 to L4 are given in Table 2. The expected increase in bone area and bone mineral content (BMC) was observed from L1 to L4. Precision error varied by individual vertebrae and by different configurations of vertebrae (Table 3). For vertebrae configurations containing at least two vertebrae, precision error ranged from 0.005 - 0.008 RMS-SD (0.44 - 0.70% CV), with the greatest precision error for L1L2. Of the individual vertebrae, the lowest (and therefore better) precision error was observed at L4, and from the different configurations, for L2L3L4 and L1L2L3L4.

Table 2. Paired Measurements of lumbar spine bone parameters across L1 to L4 Vertebrae (mean ± SD)

	BMC (g)	Area (cm^2)	BMD (g/cm^2)	Z-score
L1 Measurement 1	13.05 ± 2.72 (8.68 to 18.01)	11.47 ± 1.35 (8.36 to 13.79)	1.135 ± 0.171 (0.799 to 1.430)	0.08 ± 1.4 (-2.8 to 2.4)
L1 Measurement 2	13.01 ± 2.76 (8.38 to 17.94)	11.52 ± 1.38 (8.23 to 14.08)	1.125 ± 0.172 (0.791 to 1.445)	
Difference (M1 - M2)	*-0.04 ± 0.25* *(-0.47 to 0.60)*	*0.06 ± 0.24* *(-0.29 to 0.77)*	*-0.010 ± 0.014* *(-0.056 to 0.015)*	
L2 Measurement 1	15.39 ± 3.06 (10.3 to 21.4	12.40 ± 1.30 (8.89 to 14.76)	1.237 ± 0.180 (0.899 to 0.1.575)	0.3 ± 1.5 (-2.5 to 3.1)
L2 Measurement 2	15.44 ± 3.04 10.16 to 21.75	12.44 ± 1.35 9.11 to 15.19	1.237 ± 0.181 0.898 to 1.603	
Difference (M2 - M1)	0.05 ± 0.29 (-0.72 to 0.63)	0.04 ± 0.21 (-0.33 to 0.43)	0.000 ± 0.015 (-0.032 to 0.028)	
L3 Measurement 1	17.85 ± 3.50 (11.03 to 24.02)	13.79 ± 1.46 (10.64 to 16.44)	1.288 ± 0.175 (0.989 to 1.612)	0.8 ± 1.4 (-1.8 to 3.4)
L3 Measurement 2	17.85 ± 3.53 11.23 to 24.87	14.40 ± 2.92 10.91 to 15.94	1.284 ± 0.173 0.982 to 1.614	
Difference (M1 - M2)	*0.01 ± 0.38* *-0.52 to 1.17*	*0.04 ± 0.29* *-0.57 to 0.72*	*-0.004 ± 0.016* *-0.035 to 0.035*	
L4 Measurement 1	19.22 ± 3.53 (12.39 to 24.97)	15.86 ± 1.61 (12.20 to 19.50)	1.209 ± 0.173 (0.803 to 1.536)	0.1 ± 1.4 (-3.1 to 2.8)
L4 Measurement 2	19.29 ± 3.59 11.97 to 24.32	15.90 ± 1.64 11.68 to 19.60	1.210 ± 0.172 0.805 to 1.545	
Difference (M1 - M2)	*0.06 ± 0.44* *-0.77 to 0.91*	*0.04 ± 0.43* *-0.84 to 0.92*	*0.001 ± 0.012* *-0.026 to 0.024*	

BMC: bone mineral content; BMD: bone mineral density

Table 3. BMD precision of different PA lumbar spine vertebrae configurations

Vertebrae Configuration	Precision		Least Significant Change	
	RMS-SD (g/cm^2)	%CV	RMS-SD (g/cm^2)	%CV
1 Vertebrae				
L1	0.012	1.10	0.033	3.05
L2	0.010	0.80	0.029	2.21
L3	0.012	0.90	0.032	2.56
L4	0.009	0.73	0.024	2.01
2 Vertebrae				
L1L2	0.008	0.70	0.023	1.94
L1L3	0.008	0.67	0.023	1.86
L1L4	0.008	0.68	0.022	1.88
L2L3	0.008	0.60	0.021	1.66
L2L4	0.007	0.57	0.020	1.58
L3L4	0.006	0.51	0.017	1.42
3 Vertebrae				
L1L2L3	0.007	0.53	0.018	1.48
L2L3L4	0.006	0.44	0.015	1.23
L1L3L4	0.006	0.49	0.016	1.36
L1L2L4	0.007	0.57	0.019	1.57
4 Vertebrae				
L1L2L3L4	0.005	0.44	0.015	1.23

Discussion

This study reports differences in precision error across individual vertebrae and varying configurations of vertebrae for BMD measurement from the PA lumbar spine scan. The ISCD recommend that at least two vertebrae must be used to make a clinical diagnosis on BMD from the lumbar spine scan (1). Our data indicate that precision errors were lowest when using configurations of at least two vertebrae compared to using just a single vertebrae, and therefore support the ISCD recommendation. The precision errors for the vertebral configurations of L2 to L4 and L1 to L4 were identical, and lowest of all measurements. Precision values in the current study differ from those provided by Krueger (6, 13): (Hind et al., 2010 (2): RMSD-SD (%CV) = 0.006gm/cm^2 (0.44%) compared to Krueger et al., 2012 (6) 0.020gm/cm^2 (0.65%). Both studies used the same procedures and the same DXA manufacturer in the precision evaluation. The observed differences likely reflect the age difference between the two groups: 36.3 ± 6.5 years compared to 69.6 ± 4.9 years (Table 4), and the higher probability of vertebral degenerative changes with increasing age. Body size differences might also reflect the differences in precision. This supports the need for precision studies that are reflective of a centre's usual scanning population. Our findings support the recommendation that region L1 to L4 should be used for lumbar spine BMD assessments when vertebral exclusion is not necessary (1), but our data also indicate that region L2-L4 is equally acceptable since precision values are comparable L2-L4: RMS-SD = 0.006g/cm^2 (%CV = 0.44%), L1-L4: RMS-SD = 0.005g/cm^2 (%CV=0.44%).

Table 4. Comparison of GE iDXA lumbar spine BMD precision studies in older and younger study populations

Author	Study population	Mean age(y) ± SD	PA Spine	Mean BMD ± SD	Precision		LSC	
					RMS-SD	%CV	RMS-SD	%CV
Hind et al., (2010)	52 (34F/18M)	34.8 ± 8.4	L2 – L4	1.271 ± 0.160	0.006	0.41	0.017	1.15
			L1 - L4	1.243 ± 0.150	0.004	0.41	0.011	1.15
Hind and Oldroyd (present study)	30F	36.3 ± 6.5	L2 - L4	1.244 ± 0.169	0.006	0.44	0.015	1.23
			L1 - L4	1.217 ± 0.168	0.005	0.44	0.015	1.23
Krueger et al., (2012)	30F	69.6 ± 4.9	L1 - L4	1.116 ± 0.130	0.020	0.65	0.056	1.81
Krueger et al., (2014)	90M	75.8 ± 7.3	L1 - L4	1.137 ± 0.257	0.016	-	0.045	-
	90F	73.9 ± 6.2	L1 – L4	1.131 ± 0.189	0.016	-	0.045	-

Least significant change (LSC) = 2.77 * Precision

Although the highest LSC %CV of 3.05% CV (RMS-SD 0.033 g/cm^2) was observed for the individual measurement of L1 BMD, this did not exceed 5.3% CV LSC which is the ISCD recommended upper limit for acceptable precision for the lumbar spine (L1-L4): %CV = 1.9% (LSC = 5.3%) (1). The lowest

LSC at the individual level was 2.01% CV (RMS-SD 0.024 g/cm^2) observed at L4. This would suggest that at least with the GE Lunar iDXA, BMD measurements of individual vertebrae between L1 and L4 may be possible for monitoring in cases where all other vertebrae are excluded due to FSD or artefacts. However, whether these findings are similar for other study groups (including postmenopausal subjects) and for other instruments remains to be determined.

The approach used to assess BMD precision in the current study reflects the ISCD consensus recommendations, which is the established clinical standard. However, it should be considered that measuring only short-term precision, which only measures the machine variability and does not estimate any biological effect, may underestimate true BMD variability (14, 15). Additional limitations of this study include the small sample size and sex-specific study group. None-the-less, it has been shown previously that precision error and LSC do not vary significantly between the sexes (13). The age range of the study group was between 24 and 49 years, and this age range was included because it reflected the usual scanning population of the centre. The reasons for bone density scan referrals in younger women can include primary or secondary amenorrhea, fragility fracture, medications associated with bone loss, or a disease associated with bone loss. Finally, the results were derived from only a single manufacturer's densitometer, therefore should not be generalised to instruments of other manufacturers. As such, manufacturer and model specific precision studies are needed to enable comparisons.

In conclusion, this study demonstrated excellent precision for BMD measurements of individual and various configurations of vertebrae of the PA lumbar spine in women aged 24 to 49 years, using the GE Lunar iDXA densitometer.

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